Бюллетень Почвенного института им. В.В. Докучаева. 2019. Вып. 96.
Dokuchaev Soil Bulletin, 2019, 96

UDC 631.4, 910.27, 528
DOI: 10.19047/0136-1694-2019-96-3-21

Cite this article as:
Minayev N.V., Nikitin A.A., Kozlov D.N., The scale levels identification for the plowland topography organization, Dokuchaev Soil Bulletin, 2019, V. 96, pp. 3-21, DOI: 10.19047/0136-1694-2019-96-3-21

THE SCALE LEVELS IDENTIFICATION FOR THE PLOWLAND TOPOGRAPHY ORGANIZATION

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Received 02.11.2018, *Revised* 02.11.2018, *Accepted* 12.03.2019

The identification of factor and indicational features, which are characterized by the high informativity and field of view in relation to the soil cover organization, plays a very important role in the soil mapping. Such characteristics are more common for Unmanned Aerial Vehicles (UAV), which include spectrazonal imagery and digital elevation model (DEM) with ultrahigh spatial resolution, necessary for obtaining fine and large scale images. However, the agrogenic micro- and nanotopography is considered as a noise during the studies of the soil cover topographic differentiation under the conditions of plowland, as the genetic soil properties correlate with natural micro- and mesotopography. A filtration algorithm for the land surface roughness, which is not related to the spatial organization of the objective soil properties, is suggested in the paper. The stages of linear dimension identification for self-similar structures of the glacial and agrogenic topography based on two-dimensional Fourier decomposition are demonstrated using the example of a field topography digital model for the area of 125 hectares. Filtering in the frequency domain allowed restoring the natural field topography and substantiating the effective resolution of the

DEM and the size of the area to calculate local morphometric specificities of the topography for digital soil mapping.

Keywords: geomorphometry, digital elevation model, UAV survey, Fourier analysis, Vladimirskoe Opolye.

INTRODUCTION

The development of technical means to collect spatially distributed information about soil-formation factors enhances soil mapping capability (Minasny, McBratney, 2016). In the scale of 1:10,000 and larger the use of satellite positioning devices, laser surveying, aerospace and subsurface sounding allows a considerable expansion in soil survey coverage while maintaining its detail. This increases the detection area of soil cover organization and the visibility of detailed soil maps (Gruijter et al., 2016; Guenette, Hernandez-Ramirez, 2018; Eltnera et al., 2018; Brogi et al., 2019).

The promising technical means include unmanned aerial vehicles (UAVs), equipped with remote recording systems of soil surface (Savin, 2015; Eltnera et al., 2018). In addition to a highly-precise spectra-zonal image of ground cover (1 m and more detailed) the photogrammetric image processing makes it possible to receive a digital elevation model. These products of UAV-shooting constitute a base for soil mapping, since the topography is traditionally viewed as a lead differentiation factor of soil cover on local level and the remote image – as an indicator of its heterogeneity. However, as with any technology, the use of UAV for soil mapping tasks requires methodical study. The actively investigated issues are ones about the accuracy of digital surface models obtained under different conditions of UAV flight and shooting modes (Shinkevich et al., 2015), photogrammetric processing algorithms of UAV-recording materials and filtering of digital surface model for noise suppression (Akar, 2017; Ruzgiene et al., 2015; Zeybeka, Şanlıoğlu, 2019), use of non-simultaneous UAV-recording while monitoring natural processes (Eltner et al., 2014; Woodget et al., 2015), crop state and soil productivity (Savin, 2015; Capolupo et al., 2015).

In this article we propose an algorithm to identify scale levels of ground surface organization based on a digital elevation model (DEM) of a particular field. In terms of the plowland the field surface is a plurality of roughness of different spatial size and genesis (Eltnera et al., 2018). Thus the nanotopography (1 m) is the result of mechanical tillage (lumps, ridges, furrows, etc.), the microtopography (1–10 m) is the result of long-term agrogenic topography transformation (back ridges and back furrows) and natural exogenous processes (suffosion and thermocarstic depressions, hollows, erosion furrows, etc.), the mesotopography (10–100 m.) – ice, fluvial-glacial and erosion genesis form. With an evidence of the idea about scale levels of topography organization their identification in the specific regional conditions is associated with a significant uncertainty (Puzachenko et al., 2002). The importance of formalizing when we determine the scale levels is manifested in the problems of modeling of soil-landscape links and automatic soil maps creation.

Indeed, agrogenic nano- and microtopography, as an active factor in relation to the current elementary soil processes, is not informative when it comes to the explanation of spatial variation of soil-forming products with long formation period (profile structure and other neoplasms). Spatial variability of such conservative soil properties is predetermined by micro- and mesotopography of natural origin.

In connection with this methodical substantiation for identification methods of large-scale topography levels of different genesis on the basis of the UAV-survey data is relevant for studying the soil cover spatial diversity and mapping it. That is what this article is devoted to.

MATERIALS AND METHODS

The work was carried out on the key plot of the plowland of the former Uchkhoz K.A. Timiryazev "Druzhba" Pereslavl district, Yaroslavl region. The area refers to the northern spurs of Klin-Dmitrovskaya ridge and represents the medium and poorly-broken low-angle wavy secondary moraine plain with loam covering which capacity exceeds 2 m. The soils with the second humus horizon which are confined to negative elements of paleo-cryogenic and fluvial microtopography (Rubtsova, 1974; Makeev, Dubrovina, 1990; Alifanov, Gugalinskaya, 1993) take a big part in the soil cover structure. These regional characteristics of soil-landscape links exactly determine the interest for identification at detailed soil survey of topography microforms.

In the plot of 125 hectares there was held a survey from UAV Geoskan Agro-201 (Russia). The flyby took place in late May on a sunny and clear day when the soil surface was open. The shooting from the height of 200 m was made in four channels using RGB and NIR cameras with a resolution of 5 cm on-site. Highly accurate coordinate connection of each image is provided by using the differential system of satellite positioning as a part of the base station Stonex SIII + Topcon B110 receiver on the UAV board. Automatic stitching of flyby scenes and photogrammetric works is executed in PhotoScan[1] program. Primary material of digital photogrammetry of images stereo pairs is represented by a dot cloud of relative heights at the density of 4 dots per 1 m^2. The dot cloud is masked by field boundaries to eliminate the elevation points of vegetation. Interpolation of ground surface elevation dots for the grid of 0.25 m was held by ordinary kriging method in SAGA program.

With the total height drop of 29 m the field topography (Fig. 1) includes a sub-horizontal surface and gentle slopes of the northern and southern exposure (mesotopography elements of moraine origin). They are complicated with linear forms of different size and origin. Oriented downhill shallow gullies are of fluvial origin (Eremenko, Panin, 2010) and identified with microtopography forms. Nano- and microforms with amplitude of 10–30 cm, genetically related to mechanical soil tillage, expressed in sub-latitudinal direction.

[1] AgiSoft PhotoScan Professional Software, version 1.3.4 – http://www.agisoft.com/downloads/installer/

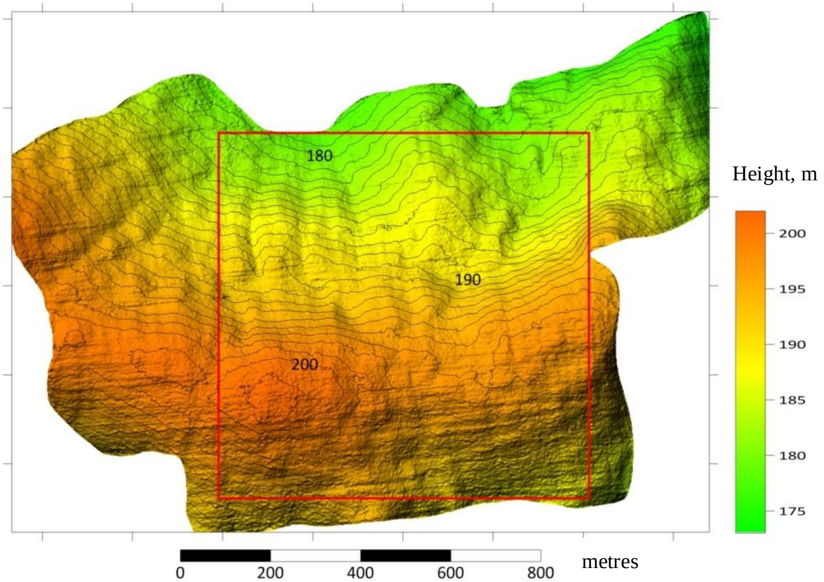

Fig. 1. Topography digital model with a square area of spectral analysis.

When studying topographic differentiation of soil cover the agrogenic topography acts as a noise. Simple filtering algorithms in the sliding window do not suppress it completely, which determine the use of spectral analysis methods for this purpose (Puzachenko et al., 2002; Turcott, 1992; Wieland, Dalchow, 2009).

Spectral analysis decomposes spatial oscillations of absolute or relative topography heights on the frequencies and determines the amplitude value for each frequency. The resulting amplitude-frequency characteristic determines the period of stable spatial oscillations of heights in different topography forms and their repetitive combinations. Inverse Fourier transform in the appropriate range of linear dimensions of the spatial waves allows us to build a surface for each scale level of topography organization both separately and at random combination (Kotlov, Puzachenko, 2006; Wieland, Dalchow, 2009).

Spectral filtering comprises four steps:

1. Direct Discrete Fourier Transform (Davis, 1990) of DEM area of the size $M \times N$ pixels (Fig. 1).

$$F_{kl} = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} Z_{mn}\left(cos2\pi\left(\frac{mk}{M}+\frac{nl}{N}\right) - j\cdot sin2\pi\left(\frac{mk}{M}+\frac{nl}{N}\right)\right),$$

where F_{kl} – amplitude of harmonic oscillations, *k* and *l* – number of harmonics in the direction *X* and *Y* up to *M/2* and *N/2* respectively, Z_{mn} – height values in the respective DEM cells, *j* – imaginary unit. Two-dimensional spectrum contains harmonic oscillation amplitude of different lengths and directions (Fig. 2a). A visual representation of the amplitude-frequency characteristics is enabled by radial convolution of two-dimension spectrum (Turcott, 1992; Puzachenko et al., 2002) by averaging the oscillation amplitudes with the same period (Fig. 2b.).

Analysis of amplitude-frequency topography image to identify scale levels of its organization. Their number is determined by the amount of straight linear parts on the graph of dependence between frequency *(D)* and amplitudes *S (D)* of harmonic oscillations of the spectral decomposition (Fig. 2b). For a range of linear dimensions of self-similar topography forms it is true the degree dependence $S(D) = \alpha * D^{\beta}$, taking a linear form in a logarithmic scale of variables. The intervals of linear dimensions of scale level are defined by oscillation periods range between the bends of the graph linear parts. To increase the visibility, the search of linear sections is carried out after removing the linear trend. To determine a self-similarity of parameter β the spectrum part is approximated by a linear function of the least squares method (Zakharov, 2014). The larger the value of β the more predictably the height varies at low incremental coordinates. When $\beta = 0$ the heights change randomly from pixel to pixel and at $\beta = 2$ the change is gradual.

2. Generation of a frequency filter $H_{k,l}$ for frequencies corresponding to the range $[D_{h.f.}, \dots, D_{l.f.}]$:

$$H_{k,l} = \begin{cases} 1, & if\ D_{h.f.} \le D_{k,l} \le D_{l.f.} \\ 0, & otherwise \end{cases},$$

$$D_{k,l} = \sqrt{\left(\frac{k}{M}-\frac{1}{2}\right)^2 + \left(\frac{l}{N}-\frac{1}{2}\right)^2},$$

and its application for frequency domain DEM

$$G_{k,l} = F_{k,l} \cdot H_{k,l} \; .$$

3. Inverse Fourier transform for the surface construction of the target scale level of topography organization:

$$Z_{mn} = \sum_{k=0}^{M-1}\sum_{l=0}^{N-1}\left(\frac{G_{kl}}{MN}\right)\left(cos2\pi\left(\frac{mk}{M}+\frac{nl}{N}\right)+j\cdot sin2\pi\left(\frac{mk}{M}+\frac{nl}{N}\right)\right).$$

The spectral analysis is done for a square fragment DEM with the size of 1640 × 1640 pixels (820 × 820 m) located in the middle of the field (Fig. 1). The requirement for Fourier-decomposition for the original signal frequency is provided by consistent mirror reflection of the square DEM fragment regarding its two perpendicular sides (Fig. 2a). In this case in the power it cannot appear a spectrum of false harmonics of Fourier-decomposition, describing the abrupt change in the height on the DEM edges. Direct and inverse Fourier transform as well as filtering in the frequency domain is performed in ImageJ program 1.52c (Fiji).

In addition to determining the filtering parameters, the spectral analysis results are used to substantiate the effective DEM resolution and neighborhood sizes to calculate the local morphometric topography characteristics (Advances..., 2008). The geometric properties of the topography element forms with a length λ are determined by the size of the sliding window λ/2 (Florinsky, 2016). The linear dimensions of the proper topography forms (Puzachenko et al., 2002; Kotlov, Puzachenko, 2006) are determined by the peaks of the spectrum power graph (Fig. 2d).

RESULTS AND DISCUSSION

The graph of dependence between spectrum power and oscillation period (Fig. 2c) shows an increase in the oscillation amplitude of the heights while their size increases. When the trend is removed the graph of the rests from the regression line (Fig. 2c) shows three intervals with a linear dependence between the dimensions and the amplitude of topography oscillation.

The intervals correspond to the dimensions of self-similar topography structures generated by independent factors (Vedyushkin, 1995; Puzachenko et al., 2002; Zakharov, 2014). Topography of the I order has proper dimensions of over 27 meters with a total height difference of 22 m and a standard deviation of 6.5 m. On the researched site, it is identified with the forms of deglaciation and periglacial morphogenesis (Fig. 3a). Agrogenic topography structures of the II order include back ridges and back furrows formed by multiple soil plowing of irregular ploughing scheme. They range in size from 4 to 27 m and in height difference up to 1 m. Topography structures of the III order with dimensions less than 4 m and height difference of up to 30 cm are also of agrogenic origin, however, their amplitude-frequency characteristic is distorted by photogrammetric processing and interpolation of the elevation marks.

Thus, in the topography organization of the test field it seems reasonable to highlight two groups of self-similar morphological elements of natural and agrogenic origin with a scale boundary between them in the frequency domain of 27 m. Inverse Fourier transform in an appropriate range of spatial waves made it possible to construct the surfaces of various genesis and restore the field topography without roughness generated by mechanical soil treatment (Fig. 3a).

The additional information can be obtained from the spectrum analysis of topography of the I order in the range of 27 to 1640 m (Fig. 2d). On the background of general linear dependence between the spatial wave dimensions and the amplitude, the typical dimensions are 410, 120, 60 m (Fig. 2d).

To identify their morphometric features in tasks of digital soil mapping the local neighborhood sizes should be respectively 200, 60 and 30 m at the resolution of digital elevation model of 20 m.

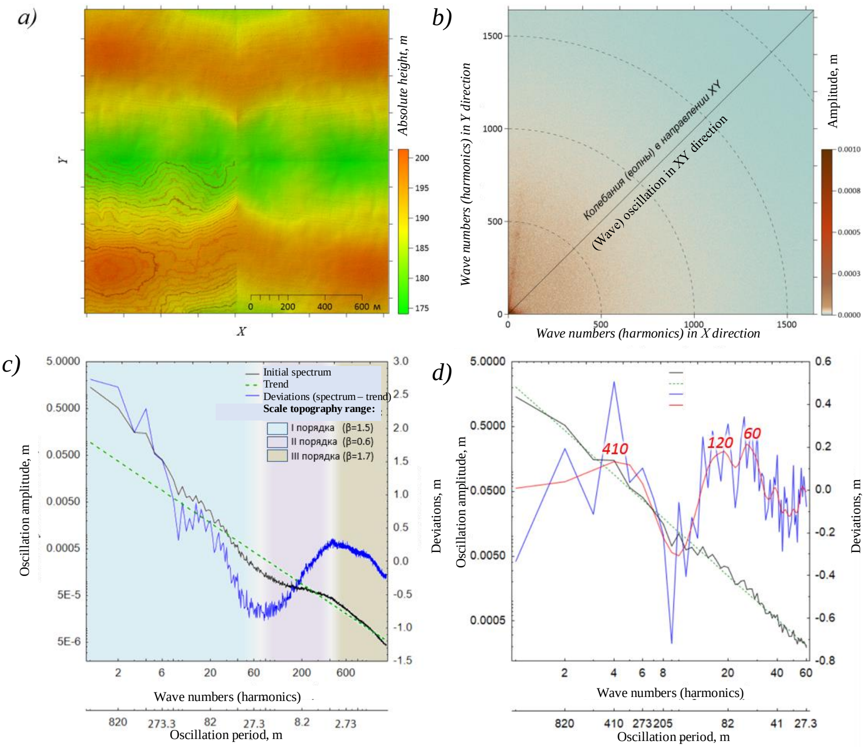

Fig. 2. Spectral decomposition stages: a) the initial topography model (1640 × 1640 pixels, the resolution of 0.5 m); b) two-dimensional Fourier spectrum; c) the radial two-dimensional spectrum convolution with the three organization scale levels of topography of I-II-III order; d) the typical dimensions for topography forms of I order.

As an example, Figure 3 shows the result of calculating topography index of excess in the neighborhood of 200 m and 30 m (Fig. 3c and 3d). The index is calculated for each element of digital elevation model as the difference between its height and the average height of the elements removed from it on a fixed distance (Weiss, 2001). The indicator characterizes surface shape and it is widely used in geo-morphometring (De Reu et al., 2013).

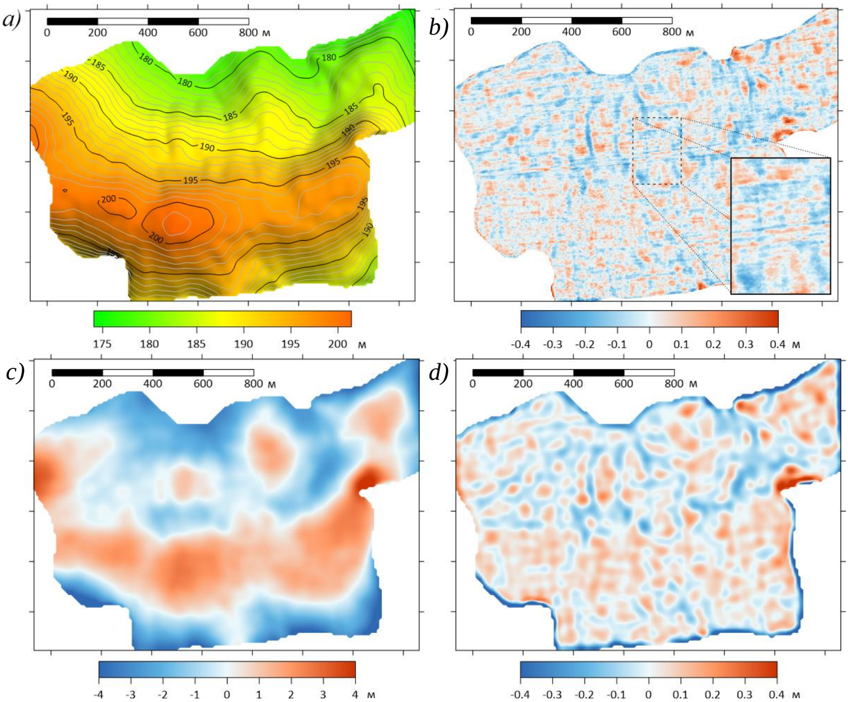

Fig. 3. Scale levels of field topography organization: a) the surface of the I order; b) the surface of the II and III orders; relative excess of surface of I order in a neighborhood c) 200 m; d) 30 m.

Relative excess in the neighborhood of 200 m and 30 m illustrates the self-similarity of topography structures of the I order of different sizes. Alternation of higher and lower round and oval forms (Fig. 3c, 3d) gives a uniform pattern that is invariant in terms of the scale. Along with that it represents the characteristics of the multiscale flow redistribution as a leading mechanism of soil cover functioning in humid soil-formation area. Other things being equal, the ratio of topography elements which scatter/concentrate the flow determines water-migration structures of soil cover at different organizational levels. In this case, differentiation of elementary soil areas potentially conjugates to redistribution of the flow according to topography forms with typical size of 60 m, and the elementary soil structures - according to topography forms with typical size of 410 m.

Figures 3b and 3c comparison shows that Fourier filtering does not provide a complete surfaces separation that are of different genesis. The filtered component (Fig. 3b) in addition to agrogenic microtopography comprises forms of natural origin, repeated in topography structure of the I order with smooth outlines (Fig. 3d). This highlights certain conventionality of division in situations where ridge and furrow microtopography commensurate the forms of depressions-hollow part. In this case, Fourier-filtering does not exclude the microforms of natural origin from field DEM, on the contrary it smooths out the height variations.

Agrogenic substitution of natural microtopography is accompanied by an increasing contrast. Alternating back furrows and back ridges with a height difference of 20–30 cm every 15–25 m forms a specific microtopography with a particular pattern (Fig. 3d). In comparison with topography of the I order its amplitude-frequency characteristic stands out for its contribution to the power of high-frequency oscillation spectrum (Fig. 2c). The coefficient of spectrum self-similarity in the range of 4–27 m ($\beta = 0.6$) three times less than in the range of 27–1640 m ($\beta = 1.5$). Low self-similarity coefficient indicates asymmetry and the fact that agrogenic forms are spread irregularly within the field, their size is uneven.

Mass materials of detailed topographic survey revealed wide contribution of ridge and furrow microtopography in the organization of plowland surface. As a consequence of non-compliance with plowing technologies (Kiryushin, 2016), agrogenic topography acts as a local factor for flow redistribution, modifies water regime of soils and intensity of associated processes of humification and mineralization of organic matter, eluviation, gleying etc. In turn, this leads to soil and soil cover transformation, increase in agro-ecological field mosaic, heterogeneity in crop development.

In this regard, the approaches to the filtering of scale-genetic levels of topography organization can be used both for the aim of digital soil mapping and the research of agrogenic transformation of soil and soil cover as well as for the evaluation of agro-environmental contrast of field microtopography in the design of intensive and high cultivation technologies.

CONCLUSIONS

1. Due to detailed scale and visibility UAV-recordings are highly informative regarding the actual diversity of plowland surface, which is undergoing an agrogenic substitution of its natural microtopography. Agrogenic ridge and furrow microtopography acts as a noise in the study of topographic differentiation of soil cover components. Simultaneously, it is an active factor in the soil and field soil cover properties transformation and in the formation of inhomogeneous agro-environmental conditions.

2. Identification of scale organization of plowland surface based on field DEM Fourier-filtering makes it possible to restore its natural topography and justify the neighborhood size to calculate local morphometric topography characteristics for the aims of digital soil mapping.

ACKNOWLEDGMENTS

The work was supported by the Basic Research Program of the Presidium of Russian Academy of Sciences “Theoretical and experimental research for effective scientific and technological development of Russian agro-industrial complex.”

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